the disassembly and recovery of materials from computers, printers, and other electronic hardware since the early 1960s. Their business is growing at the rate of 15–20% a year.

"The principal economics with a computer is in the recovery and refurbishment of the subsystems—the hard drive, the keyboard, and occasionally the monitor," says Steven Foulk, marketing executive with Handy and Harman. "The next level involves recovery of the integrated circuits and various components including the processor and memory. The final level is the recovery of precious metals including gold and copper."

Once a computer is more than 4–5 years old, Foulk says, the subsystems are generally not worth refurbishing. At that point, the value comes in "mining" the computer for its raw materials. The typical desktop computer contains about $50 worth of usable material. This includes aluminum valued at $9.37, gold at $6.45, and copper at $5.56. Unfortunately, the costs of collection, dismantling, purification, and smelting can run $45–47 per unit, making it little more than a break-even operation. Plastics, which at $12.07 per unit have the highest value of all components, present a particular problem.

"There are too many different kinds of plastics being used in most computers, which makes them difficult to separate," says Foulk. "Maybe 20 percent is recyclable, and the rest is either incinerated or landfilled."

Responding to pleas from recyclers and environmentalists, computer manufacturers are beginning to design their products with end-of-life management in mind. Two schools of design are emerging: design for the environment (DFE) and design for disassembly (DFD). IBM's Engineering Center for Environmentally Conscious Products is pioneering advances in both these fields.

"Starting in 1991, we emphasized design that used fewer materials and less energy," says J. Ray Kirby, director of the IBM center. "Within the second year, we focused on how to design to assist in recovery and recycling. Our PS/2E qualifies for the government's Energy Star Logo. It tak7es less energy to run than most PCs and the plastic cover has 25 percent recycled content."

IBM has only a limited take-back program. The company operates a number of collection centers in Europe, which has a more aggressive stance on take-back. Computers are sent to Scotland where the keyboards are melted down and remolded. In the United States, IBM is piloting some programs to evaluate the costs of take-back, but these are not yet available to all customers.

Joseph Tart

Will not compute. Rather than shelving the problem of what to do with outdated computer equipment, several companies are pushing for recycling and reuse.

Hewlett-Packard operates product recovery centers in Roseville, California, and Grenoble, France, which together retrieve nearly 800,000 pounds of computer and related equipment each month. Products are disassembled and sorted into types of components. Reusable and resalable parts, such as computer chips, are recovered and refurbished. The remaining parts are recycled to the maximum extent possible.

Apple sponsors periodic trade-in programs for its personal-use computers through colleges and universities. Students can receive a $250 discount on a new Apple computer or printer when trading in an older model. Computers are sent to Fox Electronics in San Jose, California, which recovers the integrated circuits and sends other components to other recycling firms. Apple's most recent buy-back program netted over 15,000 computers.

Recyclers identify four major problems that must be addressed if computer recycling is to make significant inroads. First, computers need to be designed for easier disassembly, which currently runs about $20 per desktop computer in labor costs alone. Second, separation systems for mixed plastics need to be developed. Third, recycling efficiency for metals needs to be improved. And finally, recycling processes need to be developed for elements, particularly exotic elements such as rhodium and terbium, which are not currently being recycled, but which may become critical because rare elements are used in advanced computing systems.

"For recycling to be effective, the infrastructure to take computers apart has to be as big as the manufacture," says Foulk. "The infrastructure for recovery of the metals is in place. The infrastructure for dismantling and recovering subsystems that still have value is developing. Collection and transportation is in its infancy."

Measuring UV's Effects

Long-term exposure to UV-B rays, the spectrum of sunlight with a wavelength shorter than 320 nanometers, is known to contribute to a variety of human ailments including premature aging of the skin, nonmelanoma skin cancer, and cataracts. It is also suspected to play a role in melanoma skin cancer and suppression of the immune system. Stratospheric ozone is the most important factor determining the amount of UV-B radiation reaching the earth's surface. Concern about human exposure to UV-B has been increasing since decreases in atmospheric ozone were discovered over Antarctica in 1985. Unfortunately, there is no worldwide network for measuring changes in UV radiation, so there is no clear understanding of how much UV radiation is increasing in different locales, or whether such increases might be responsible for observed changes in biota. But that situation is about to change.

In coordination with the U.S. Global Change Research Program, the EPA has installed spectroradiometers—devices that will provide long-term data on the UV-B flux reaching the earth's surface—in five cities in the United States: Atlanta, Georgia; Research Triangle Park, North Carolina; Gaithersburg, Maryland; Boston, Massachusetts; and Bozeman, Montana. Data from these devices will be useful in studies ranging from the effects of UV-B flux on the incidence of cataracts to the failure of striped bass eggs to reach maturity.

The device, called a Brewer spectroradiometer, is capable of measuring radiation across the UV range in half-nanometer wavelengths. Spectroradiometers provide continuous measurements, feeding data automatically into computers inside the buildings on which the instruments are installed. Continuous measurement is crucial since most biologic effects from UV-B are sensitive to accumulated doses rather than a threshold dose. The main advantage of spectroradiometers over other UV-monitoring instruments is that the biologic effectiveness for any spectrum can be calculated. Additionally, the details of the spectrum bear vital information about the composition of the atmosphere, such as total ozone column, total oxygen saturation column, and particle scattering, all of which affect the amount of UV-B reaching the earth's surface. The relationship between these various phenomena are complex and not well understood. Ground-based UV measurements, coupled with other meteorological data such as cloud cover, are necessary to explore atmospheric changes and the resultant effects on the biosphere.

"Until now, the data has not been good enough to resolve the many issues with respect to changes in the UV-B flux," says Larry Cupett, acting director of the EPA's Atmospheric Processes Research Division. "We know that changes in the total ozone column can influence the amount of UV-B reaching the earth's surface. But is there a long-term trend? What is the influence of cloud cover, particulate scattering, and ozone in the planetary boundary layer? Until you understand all the parameters, you can't identify which ones will have long-term effects. And until we get a technique that can accurately measure UV-B, the correlations with various biological effects will be suggestive."

Project scientists estimate they will need at least 5–7 years' worth of data to begin to detect long-term changes. Data gathered from each site will be posted on the World Wide Web under the EPA's home page beginning later this year. Additional cities will be included if funding becomes available.

Menace in the Mix

New research underway at Duke University could yield clues to how chemicals used by U.S. soldiers during the Persian Gulf War may have intermingled and caused neurotoxic effects in some veterans. The combined, or synergistic, effects from three chemicals: pyridostigmine bromide, DEET, and permethrin, may have caused some of the symptoms reported by Gulf War veterans, including chronic fatigue, rashes, headaches, weight loss, and joint pain, according to Mohamed Abou-Donia, a professor of pharmacology at Duke University who is spearheading the research.

"It's a plausible hypothesis that synergism occurred," says Ernest Hodgson, head of the toxicology department at North Carolina State University, who has devoted much of his work to studying the synergism of chemicals. "That's not to say [the hypothesis] is an appropriate lead for further investigation," Hodgson cautions. "Dramatic cases of synergism are really not that common."

Abou-Donia's preliminary findings are arresting, however: they show that, when introduced alone, the chemicals caused no harmful effects on laboratory animals. However, when the chemicals were administered two or more at a time, the animals underwent significant neurological damage. Abou-Donia and his colleagues, toxicologist Ken Wilmarth and biochemist John Locklear, tested the chemicals on chickens because they are more sensitive than rats to chemicals that harm the central nervous system and because federal agencies call for the use of chickens when screening chemicals for possible neurological effects.

Findings from Abou-Donia's research, due to be published soon, may supply at least one missing link in the chain that may one day conclusively tie a number of symptoms reported by Gulf War veterans to environmental exposures they suffered during the war. Soldiers there endured environmental hardships ranging from oil well fires and infectious parasites to pesticides, insecticides, and anti-nerve gas pills originally intended to protect them. Abou-Donia's research is being funded by a grant from former presidential candidate and veterans' advocate H. Ross Perot.

Ironically, the three chemicals being evaluated at Duke were issued by the Department of Defense to protect soldiers. At the outset of the conflict, U.S. and British troops were given a 21-count package of 30-mg pyridostigmine bromide, anti-nerve gas pills that would counter the effects of potential Iraqi chemical warfare. "It shields an enzyme present in the brain and peripheral nervous system in a reversible manner, for a short period of time," says Abou-Donia, explaining how the chemical functions.

Though the DOD and a Defense Science Board Task Force on Gulf War Effects concluded in their 1994 report that the Iraqis did not use chemical or biological weapons against coalition forces, rumors of chemical warfare apparently circulated widely among soldiers throughout the conflict. According to Abou-Donia, fear prompted many soldiers to take more than the recommended dosage of pyridostigmine bromide pills. "During the war, over 50 percent of U.S. service personnel seen in the health service complained of symptoms relating to pyridostigmine bromide," Abou-Donia says.

The other two chemicals Abou-Donia and his colleagues are studying are *N,N*-diethyl-*m*-toluamide (DEET), an insect repellent, and permethrin, a liquid insecticide. According to Abou-Donia, DEET (used in a 90% concentration) was used due to concern about insect-borne tropical illnesses. Soldiers' uniforms were impregnated with permethrin, says Abou-Donia. Some veterans have reported that combat uniforms were doused with the liquid, then distributed in plastic bags. Because soldiers would presumably wear the uniforms for an extended time—a period of days, perhaps—extensive dermal contact with the permethrin would have occurred. Both DEET and permethrin have low acute toxicity, Abou-Donia says. "If the two chemicals had been given alone, they would not have caused harm," he quickly points out. In 1992, New York state banned the use of insect repellents containing more than 30% concentrations of DEET because of concerns over health effects (see *EHP*, vol. 102, no. 11, p. 910).

To test the combination of chemical exposures in the lab, the researchers administered pyridostigmine bromide orally and both the DEET and permethrin dermally via subcutaneous injection. Though soldiers in the battlefield would have absorbed the latter two chemicals dermally, Abou-Donia and his colleagues had to inject the chickens subcutaneously to deliver precisely measured and statistically viable quantities.

Abou-Donia's team is also investigating the hypothesis that the chemicals the Gulf War soldiers were exposed to generated a delayed toxic impact known as organophosphate-induced delayed neurotoxicity (OPIDN). OPIDN assaults both the central and peripheral nervous systems, producing symptoms such as weak-